AD 701 398

WEATHER TRACKING WITH THE AFCRL EXPERIMENTAL 3-D RADAR

W. G. Mavroides

Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

January 1970

AD 701398

AFCRL-70-0006
JANUARY 1970
INSTRUMENTATION PAPERS, NO. 163

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Weather Tracking With the AFCRL Experimental 3-D Radar

W. G. MAVROIDES

OFFICE OF AEROSPACE RESEARCH

United States Air Force

AFCRL-70-0006
JANUARY 1970
INSTRUMENTATION PAPERS, NO. 163

MICROWAVE PHYSICS LABORATORY PROJECT 5635
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Weather Tracking With the AFCRL Experimental 3-D Radar

W. G. MAVROIDES

OFFICE OF AEROSPACE RESEARCH
United States Air Force

Abstract

Experimental work using the AFCRL 3-D Radar, based on the Phase-in-Space principle, as a weather radar, is presented. Snow and rain storms are tracked and documented by photographs taken from a conventional Plan-Position-Indicator display scope (PPI) and compared with the presentations from the AFCRL 3-D Radar Range-Height-Indicator scope (RHI). In addition, the sensitivity and response of the Phase-In-Space principle is clearly depicted with the detection of cloud areas and separation of cloud layers of different densities. Also, evidence is presented showing the superiority of the RHI presentations in differentiating targets in the midst of storms over the conventional PPI display.

Contents

Illustrations

Weather Tracking With the AFCRL Experimental 3-D Radar

1. INTRODUCTION

Generally, in designing a radar set or system, certain requirements are set forth which are determined by the particular application that dictated the need for the radar. However, in some cases, as in research, a new principle may evolve that lends itself to a multitude of applications, and the direction of involvement is determined by the priority of projects at hand. Such is the case of the Phase-in-Space principle first delineated by Sletten in 1956 (Sletten 1963).

Briefly, the AFCRL Tri-Coordinate Radar utilizes the Phase-in-Space characteristics of the antenna pattern to extract elevation angle, thus adding a third coordinate to a large volume rapidly scanning system.

Employing this principle enables a conventional radar to obtain accurate height information along with the normal azimuth-range data usually available by changing the antenna and adding an extra receiver and phase-comparison circuitry.

In addition to detecting and pinpointing air and ground targets, the Phase-in-Space function of the antenna shows good response to distributed incoherent targets, such as hydrometeors, and readily separates weak cloud echoes from ground or sea reflections.

(Received for publication 8 December 1969)

Results and description of the radar as a height-finder have been published (Mavroides et al. 1966, Wingrove 1964). This paper deals primarily with radar used in weather identification and tracking.

2. GENERAL DESCRIPTION

2.1 Antenna System

Early work at AFCRL (Sletten, C. J. et al. 1953, 1958) on beam shaping with line source feeds showed the feasibility of using line sources in parabolic reflectors to obtain $\csc^2\theta$ coverage out to 60°. Other work revealed the wide angle focussing properties of torus reflectors (Mavroides et al. 1958). From a study of these results, an antenna system was derived consisting of a parabolic torus and a curved line source feed. The reflector (figure 1) being spherical in the vertical plane and parabolic in the horizontal plane is 11 feet high and 16 feet wide.

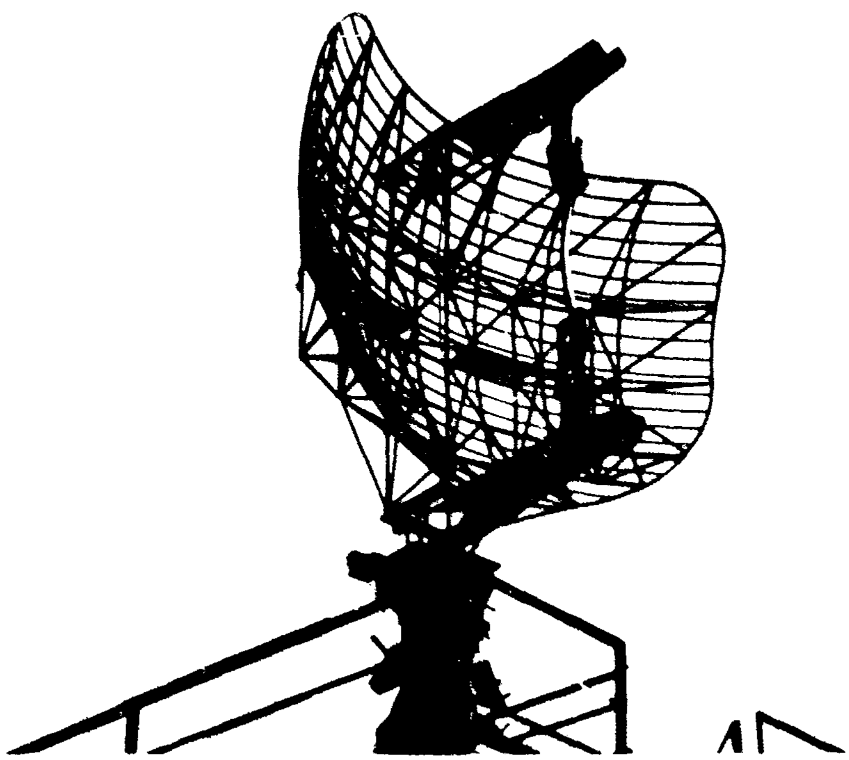

Figure 1. Parabolic Torus Antenna

The feed, placed slightly less than halfway between the reflector and the radius of curvature, is 4 feet long and has a radius of curvature of 5.5 feet. Two feeds were made for the system, one consisting of longitudinal shunt slots for horizontal polarization, the other with dipoles for vertical polarization. The beamwidth is 1.3° in the azimuth plane and has a 30° $\csc^2\theta$ shaped beam in elevation. The amplitude and phase function of the antenna pattern in space is controlled primarily by the field distribution. Thus, there is a direct correspondence between the complex antenna pattern in space and the amplitude and phase function at the primary feed. Returns from targets intercepted by the radar beam at different angles have a definite phase relationship between them. By measuring this phase in the antenna pattern and by comparing it with a reference phase, an additional angular coordinate is derived to determine the elevation angle and compute the height of the desired target.

2.2 Radar Description

Since a complete explanation of the AFCRL 3-D Radar is given elsewhere (Sletten 1956, Mavroides et al. 1966, Wingrove 1964), only a brief description of the system is given here.

A general explanation of how the radar extracts height information from a single feed, single antenna system can be made by referring to figure 2.

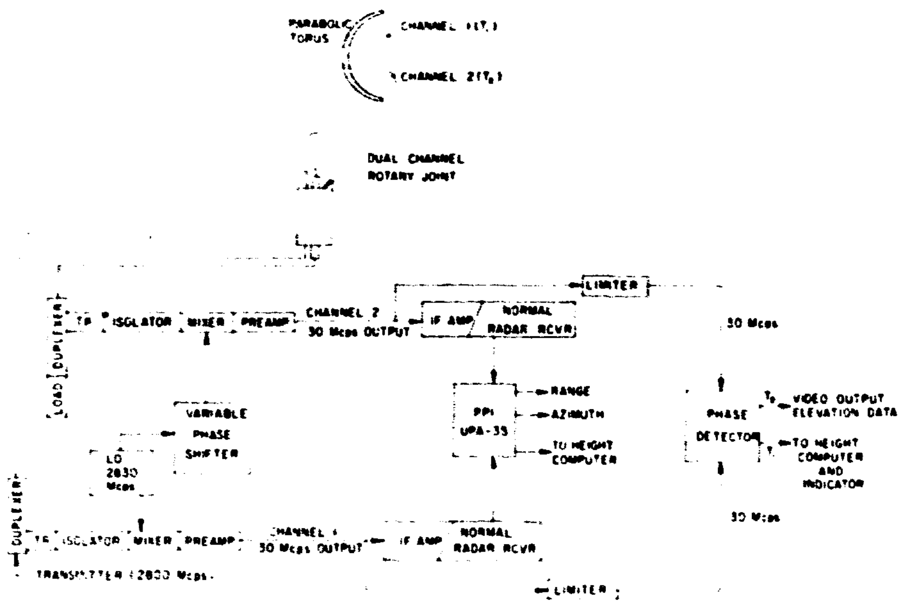

Figure 2. Block Diagram Showing Details of 3-D Radar

On transmit, a signal is fed to the traveling-wave array through duplexer D_1 and the high power channel of the rotary joint and propagates from the dipoles to form a search pattern. On receive, the energy from the target enters the feed at some point related to the angle of the target. The target return splits at this point, a portion traveling through T_1 to channel 1 of the receiver system, and the rest through T_2 to channel 2. Here the signals from the two terminals are converted to 30 mHz/sec and proceed to the receivers. Each receiver channel separates into two branches, one a conventional search radar receiver, the other a special phase detector receiver for extracting height information.

Signals from the search radar receiver are detected and displayed on a normal Plan-Position-Indicator (PPI) yielding azimuth-range information. At the same time, the signals from both ends of the feed are phase compared in the phase detector receiver. The output signal is proportional to the sine of the elevation angle (θ) of the target and is displayed on the Range-Height-Indicator (RHI) (A scope). The product of the sin θ and range voltages give a height voltage which is converted to feet. A fractional voltage is added to correct for the earth's curvature.

Several flight tests have been completed using the radar system as a height-finder. Test results (Mavroides et al. 1966) obtained show good relative height information with absolute height accuracy reduced by interference from energy reflected at grazing incidences from the ocean. The tests were made using a C-130 aircraft with the main route of track being between the tip of Cape Ann, Massachusetts and the Isles of Shoals.

During these tests, it was noticed that the Phase-in-Space function of the antenna pattern was also sensitive to distributed incoherent targets, such as hydrometeors, and readily distinguished weak cloud echoes from ground or sea reflections. This led to further investigations using the system as a weather radar.

2.3 Weather Radar Tests

Although rain echo is the sum of the reflections from a large number of drops spread out over a volume of space, enough return is present to obliterate a target on the conventional PPI scope. At the same time, however, it was possible to distinguish targets in rain on the RHI scope.

Figure 3 shows a typical target return as presented on the RHI scope. The white line across the top of the scope is the elevation cursor. When the cursor is aligned with the target by turning the elevation handwheel, a voltage proportional to the sine of the angle of the target is generated. This voltage, along with the range voltage generated by the strobe from the PPI scope, computes the height of the target.

Essentially, the center portion of the RHI scope presents random noise (phase of the receiver input noise) while above and below the noise area the screen

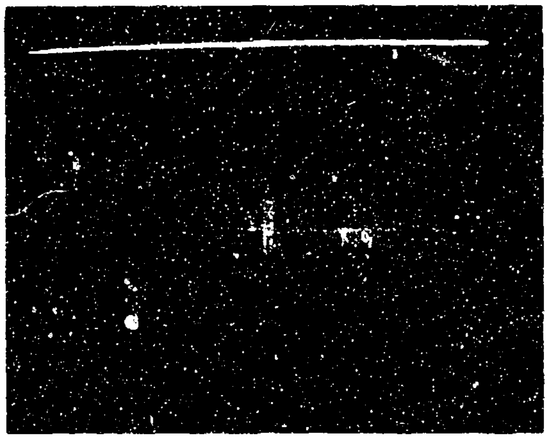

Figure 3. Typical Target Return on Range-Height-Indicator (RHI) Scope

is primarily blank except for the indication of the target. Figure 4 shows a portion of the random noise output area of the RHI scope magnified with no target return. The following photographs of the RHI scope shows only a portion of the display tube magnified unless otherwise noted.

On January 6, 1966 a storm area was detected at a range of 42.5 miles at an azimuth bearing of $\theta = 156^{\circ}$; $\theta = 0^{\circ}$ was approximately due north from our site. The picture record of the storm began at 10:21 A.M. Note on Figure 5 that the random noise area is spreading in the vertical. The return signal is filling in to the bottom of the scope. This is more evident in Figure 6 taken 8 minutes later when the storm apparently intensified. The increase in the intensity of the return testifies to this. In Figure 7 (10:40 A.M.) we see the normal PPI presentation of the azimuth sector (θ) between 161° - 200° and a range between 10-42 miles. The white line across the center of the photo is the azimuth cursor of the PPI scope while the white dot is the range strobe that is set on the target or target area desired to be displayed on the RHI scope. The range voltage used with the sine voltage to calculate

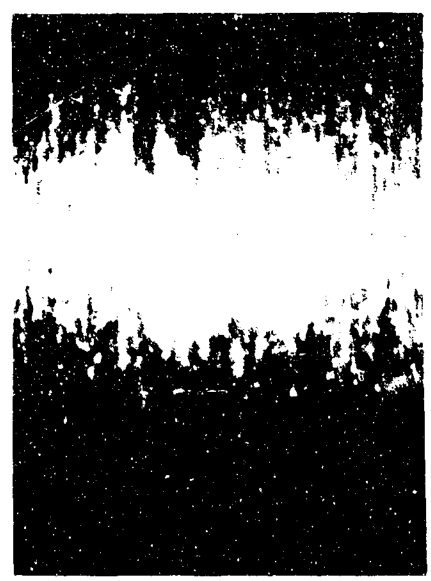

Figure 4. Random Noise on RHI Scope Magnified

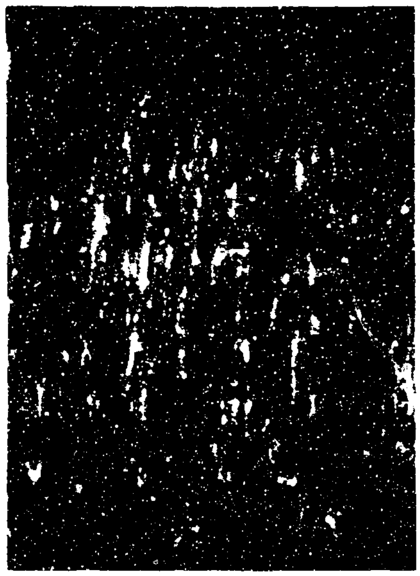

Figure 5. Random Noise with Rain - 10:21 A.M.

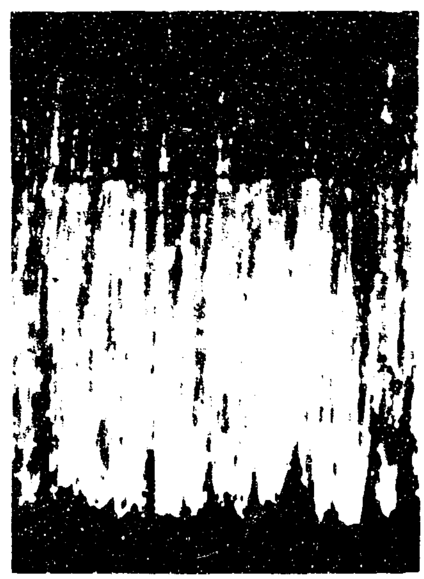

Figure 6. Intense Rain Eight Minutes Later

Figure 7. PPI Presentation of Rain Area - 10:40 A.M.

the height of the target is generated here. Figure 8 shows a ground target out in the s rm area at 11:00 A.M. (θ = 105°, Range = 12 mi.) as displayed by the height indicator.

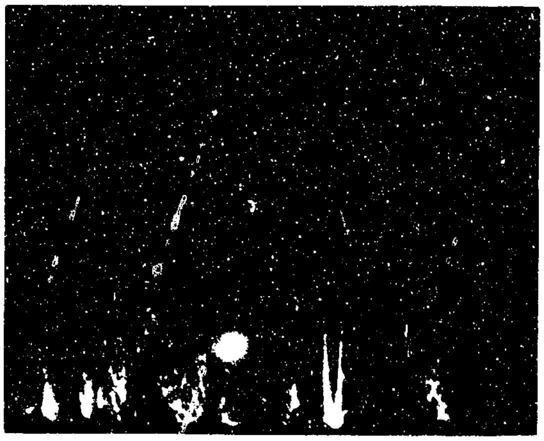

Figure 8. Ground Target in Rain - 11:00 A.M.

Since the storm ar a, south to southwest of us, was heading through our direction toward the Isles of Shoals, it was decided to photograph the Isles of Shoals (figure 9) before the storm and then follow the progress of the storm as it approached the island area. The cursor (white line at the bottom of the picture) denotes zero elevation. Note the random noise area stops about the middle of the picture while the ground targets reach clear to the bottom. The PPI scope picture of the area (figure 10) shows the Isles of Shoals (3 dots circled in white) with the range strobe (white dot with black circle around it) at the edge of the storm (θ = 35°, Range = 12 mi.). The area at the 12 mi. range at the edge of the storm (figure 10) is displayed in figure 11 (11:15 A.M.) on the RHI scope. This clearly shows the rain approaching the area. Again, the height cursor (white line) is set at zero elevation indicating the rain touching the ground, while to the right (increase in range), we see the random noise barely affected, revealing that little or no rain is present.

At 11:30 A.M. some precipitation is occurring in the Isles of Shoal area (figure 12a). We note that the radar return is filling in the region between the first two islands, with gradual return between the second and third island. No precipitation is noticeable beyond this region. By 11:42 the areas (figure 12b) between the islands are completely filled in by the radar return indicating that the storm has spread and increased in intensity. Still it is interesting to note that beyond the last island, the weather looks moderate in intensity. Six minutes later (figure 12c) we see the entire region engulfed in heavy rain. Note, however, that all targets are still clearly visible on the RHI scope, while in the PPI display (figure 13), the islands are completely wiped out by the return from the rain storm.

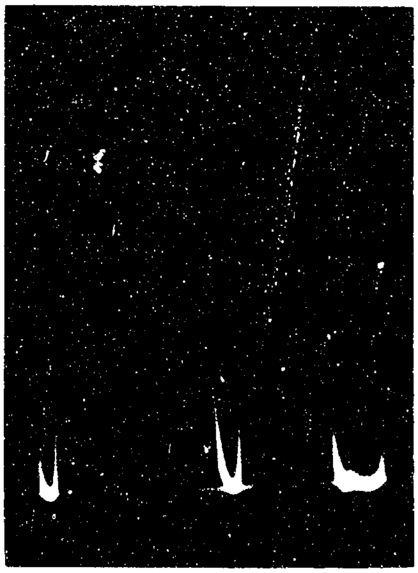

Figure 9. Isles of Shoals
RHI Presentation

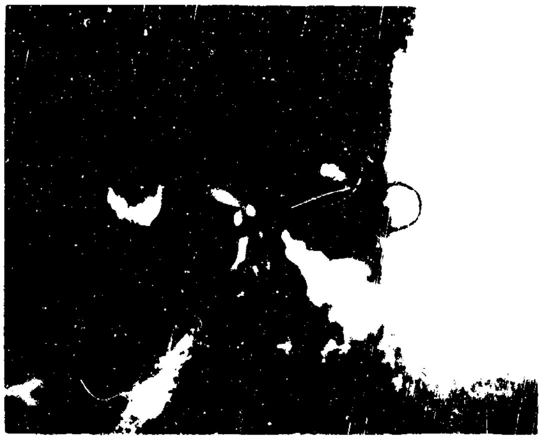

Figure 10. Isles of Shoals
PPI Presentation

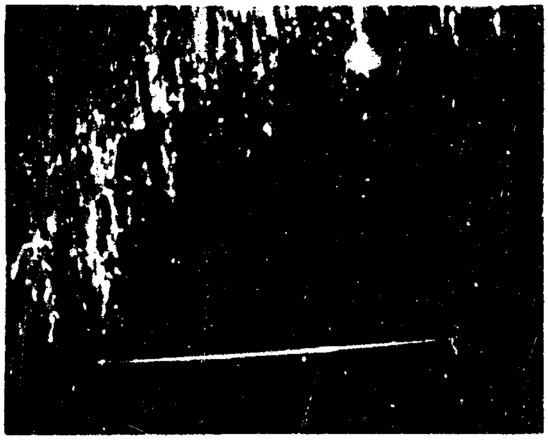

Figure 11. RHI Presentation
of Edge of Storm Area

Figure 12a. Rain Approaching Isles of Shoals - 11:30 A.M. (RHI)

Figure 12b. Rain Approaching Isles of Shoals - 11:42 A.M. (RHI)

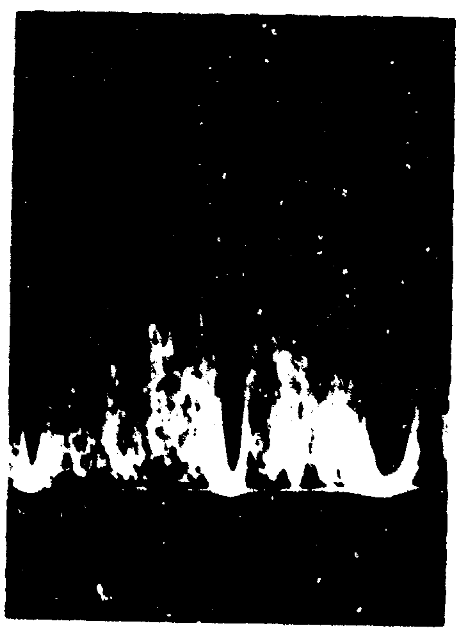

Figure 12c. Intense Rain, Isles of Shoals (RHI)

Figure 13. PPI Presentation of Isles of Shoals Engulfed in Rain Clutter

On February 4, 1966 we had occasion to witness a snow storm over the Boston area beyond the Prudential Building. In figure 14, the PPI strobe (white dot) is set on the area of snow; the largest target below and just to the right is the Prudential Building. This same area is displayed in the RHI scope (figure 15) with a ground target (Prudential Building) on the left. Later, photographs were taken of the Isles of Shoals (figure 16)(PPI Display) showing the approaching snowstorm. Figure 17 is the RHI display of the islands engulfed in snow.

Figure 14. PPI Presentation of Snow Area

Another interesting aspect of the AFCRL 3-D Radar is its response to clouds as well as to precipitation areas. Figure 18 shows a sector of the RHI scope displaying returns from clouds. The cursor indicates the elevation. Apparently, there are several cloud banks. Note the return of the targets on the right is less dense and spread over a greater area than the target on the left. This leads us to believe that cloud layers of different densities are present. Compared with the radar return from an airplane (figure 19), we note the more solid the target, the more intense and sharper the return that is displayed. Figure 20 presents an overall view of the RHI display screen showing a high flying target over terrain.

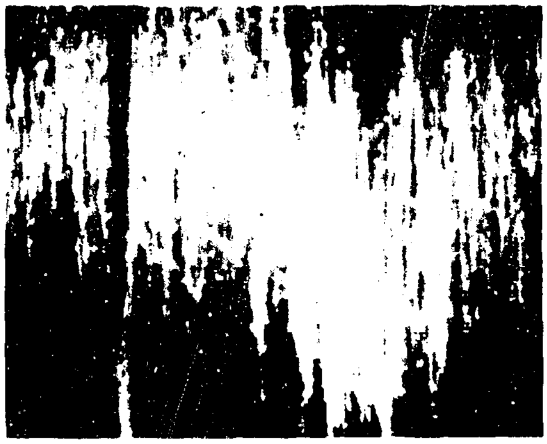

Figure 15. RHI Presentation of Snow Area

Figure 16. PPI Display of Snow Storm Approaching Isles of Shoals

Figure 17. RHI Display of Isles of Shoals Engulfed in Snow

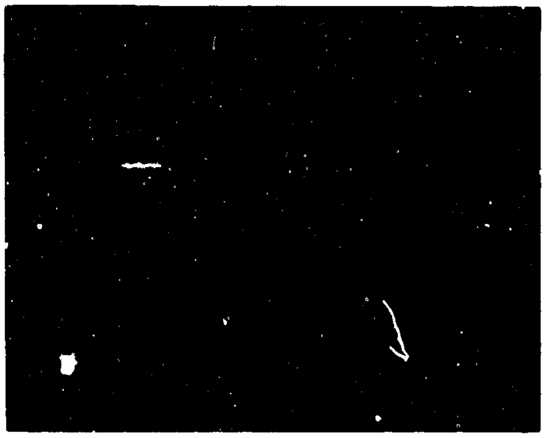

Figure 18. RHI Display of Several Cloud Banks

Figure 19. RHI Display of Airplane Target

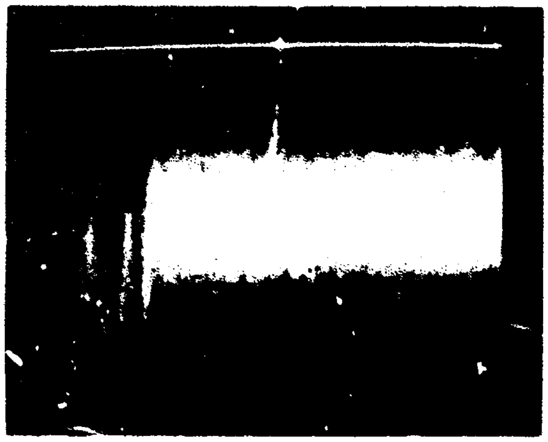

Figure 20. RHI Display of Over-All View of High Flying Airplane Over Ground Targets

3. SUMMARY

The AFCRL 3-D, 10 cm, Radar System indicates the height and range of targets instantaneously. In addition, the system is capable of detecting the height of cloud layers, the presence of precipitation, and is able to display targets in the midst of storms that may be obliterated by conventional radars.

The system is simple in design, employing a single antenna structure and feed to provide instant precision target location and wide angular coverage. These qualities make the system amenable to a variety of applications, such as mobile height finding, air traffic control, and the detection of weather and clouds.

References

Sletten, C. J. (1956) A New Technique for obtaining Tricoordinate Radar Information, Proc., Georgia Tech Schel. Symp on Scanning Antennas, pp. 321-365.

Mavroides, W. G.; Dennet, L. F.; Dorr, L. S. (1966) 3-D Radar Based on Phase-in-Space Principle, AFCRL-66-61 Instrumentation Paper No. 113 and IEEE Transactions on Aerospace and Electronic Systems, AES-2, No. 3, pp. 323-331.

Wingrove, E. R. Jr. (1964) Investigation of AFCRL Tricoordinate Radar Technique, General Electric Electronic Lab., Syracuse, N. Y.

Sletten, C. J. et al. (1953) Beam Shaping by Means of Line Sources in a Paraboloid, AFCRC-TR-53-42.

Sletten, C. J. et al. (1958) Corrective Line Sources for Paraboloids, IRE Transactions on Antennas and Propagation, AP-6, No. 3.

Sletten, C. J. (1963) Means for Obtaining Tricoordinate Radar Information, U. S. Patent 106, 708.

Mavroides, W. G., Provencher, J. H. (1958) Off Axis Sidelobe Reduction in Elliptic Torus Reflectors, AFCRC TR-58-199.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Cambridge Research Laboratories (CRD) L.G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

WEATHER TRACKING WITH THE AFCRL EXPERIMENTAL 3-D RADAR

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific. Interim.

5. AUTHOR(S) (First name, middle initial, last name)

W.G. Mavroides

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1970	19	7

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-70-0006
b. PROJECT, TASK, WORK UNIT NOS. 5635-02-01	
c. DOD ELEMENT 61102F	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) IP No. 163
d. DOD SUBELEMENT 681305	

10. DISTRIBUTION STATEMENT

1—This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Cambridge Research Laboratories (CRD) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

Experimental work using the AFCRL 3-D Radar, based on the Phase-in-Space principle, as a Weather Radar is presented. Snow and rain storms are tracked and documented by photographs taken from a conventional plan-position-indicator display scope (PPI) and compared with the presentations from the AFCRL 3-D Radar range-height-indicator scope (RHI). In addition, the sensitivity and response of the phase-in-space principle is clearly depicted with the detection of cloud areas and separation of cloud layers of different densities. Also, evidence is presented showing the superiority of the RHI presentations in differentiating targets in the midst of storms over the conventional PPI display.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Phase-in-space principle						
3-D radar						
Height-finder						
Weather radar						
Antenna						
Line source feed						
Phase comparison						

UNCLASSIFIED

Security Classification